CLAIMS

What is claimed is

Claim 1. A watercraft steer-by-wire control system comprising:

a direction control system responsive to a directional command signal for steering a watercraft, said direction control system including a rudder position sensor to measure and transmit a rudder position signal;

a helm control system responsive to a helm command signal for receiving a directional input to a helm from an operator and providing tactile feedback to an operator, said helm control system including at least one of; a helm position sensor to produce and transmit a helm position signal and a torque sensor to produce and transmit a helm torque signal;

a watercraft speed sensor for producing a watercraft speed signal;

a master control unit in operable communication with said watercraft speed sensor, said helm control system, and said direction control system;

said master control unit includes a position control process for generating said directional command signal in response to said watercraft speed signal, said helm torque signal and said helm position signal; and

said master control unit includes a torque control process for generating said helm command signal based on said helm torque signal, said helm position signal and said watercraft speed signal.

Claim 2. The watercraft steer-by-wire control system of Claim 1 further including a rudder force sensor in operable communication with said rudder control system to produce and transmit a rudder force signal and wherein at least one of said rudder control system and said torque control process is responsive to said rudder force signal.

Claim 3. The watercraft steer-by-wire control system of Claim 1 wherein said torque control process includes an active damping process wherein a damping torque command signal is generated based on a time rate of change of said helm position signal and modified by said helm torque signal and said watercraft speed signal.

Claim 4. The watercraft steer-by-wire control system of Claim 1 wherein said torque control process implements a compensator to configure spectral content of a damping torque command signal thereby generating a compensated torque command signal, said compensator is configured to facilitate at least one of a modification of the spectral content of said tactile feedback and maintaining stability of said watercraft steer-by-wire control system.

Claim 5. The watercraft steer-by-wire control system of Claim 1 wherein said torque control process further implements a feel process comprising an assist sub-process responsive to a compensated torque command signal and said watercraft speed signal, which generates an assist torque command and a return sub-process responsive to said helm position signal and said watercraft speed signal, which generates a return torque command.

Claim 6. The watercraft steer-by-wire control system of Claim 1 wherein said position control process calculates and produces a variable steering ratio signal in response to said helm position signal, said helm torque signal, and said watercraft speed signal.

Claim 7. The watercraft steer-by-wire control system of Claim 1 wherein said position control process further comprises a directional command process that calculates a theta correction and generates a theta corrected directional command signal from a variable steering ratio signal, said helm torque signal, and said helm position signal.

Claim 8. The watercraft steer-by-wire control system of Claim 1 wherein said tactile feedback includes at least one of: reaction torque to

an operator; an on center detent as a helm moves thru a center position; and variable control stops to resist helm motion beyond a selected threshold.

Claim 9. The watercraft steer-by-wire control system of Claim 1 wherein said helm control system comprises a closed loop control system responsive to said helm command signal and said helm torque signal.

Claim 10. The watercraft steer-by-wire control system of Claim 1 wherein said helm control system configured to exhibit a bandwidth sufficient to facilitate said torque control process maintaining stability of said watercraft steer-by-wire system.

Claim 11. The watercraft steer-by-wire control system of Claim 1 wherein said helm control system comprises a helm control unit and a helm dynamics unit; said helm control unit is responsive to said helm command signal and said helm torque sensor signal and generates a torque command signal; said helm dynamics unit is responsive to said torque command signal and provides said tactile feedback in response thereto to an operator.

Claim 12. The watercraft steer-by-wire control system of Claim 11 wherein said helm control unit includes a compensator configured to characterize spectral content of said torque command signal to facilitate at least one of maintaining stability of said helm control system and increasing bandwidth of said helm control system.

Claim 13. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system is configured to exhibit a bandwidth sufficient to facilitate said position control process maintaining stability of said watercraft steer-by-wire system.

Claim 14. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system comprises a closed loop control system responsive to said directional command signal and said rudder position signal.

Claim 15. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system comprises a rudder control unit and a rudder dynamics unit; said rudder control unit is responsive to said directional command signal and a rudder position signal and generates a position command signal; said rudder dynamics unit is responsive to said position command signal and provides a rudder position in response thereto.

Claim 16. The watercraft steer-by-wire control system of Claim 15 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal to facilitate at least one of maintaining stability of said direction control system and increasing bandwidth of said direction control system.

Claim 17. The watercraft steer-by-wire control system of Claim 1 further including a lateral thruster in operable communication and cooperation with a rudder dynamics unit directing thrust to provide at least one of substantially lateral control and substantially yaw control to facilitate at least one of low speed and docking operations; wherein said lateral thruster is responsive to at least one of a port command and a starboard command.

Claim 18. The watercraft steer-by-wire control system of Claim 1 further including an inclination control system comprising:

an inclination sensor in operable communication with said master control unit;

at least one of an I/O trim and a trim tab, with an actuator in operable communication with said master control unit; and

wherein said master control unit provides a trim command to said trim tab to control watercraft inclination.

Claim 19. The watercraft steer-by-wire control system of Claim 18 wherein said trim tab comprises a port trim tab and starboard trim tab to facilitate lateral inclination control.

Claim 20. A method for directing a watercraft with a watercraft steer-by-wire system comprising:

receiving a watercraft speed signal;

receiving a helm position signal;

receiving a helm torque sensor signal;

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm torque signal, said helm position signal, and said watercraft speed signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said watercraft speed signal, said rudder position signal, and said helm position signal to control direction of said watercraft.

Claim 21. The method for steering a watercraft of Claim 20 further comprising:

receiving a rudder force signal and wherein said a helm command signal is also based on said rudder force signal; and

generating a directional command signal to a direction control system based on said watercraft speed signal, said helm position signal, and at least one of said rudder position signal and said rudder force signal.

Claim 22. The method for steering a watercraft of Claim 20 further comprising:

generating damping torque command signal responsive to said helm torque signal, said helm position signal and said watercraft speed signal; wherein said damping torque command signal is responsive to a time rate of change of said helm position signal.

Claim 23. The method for steering a watercraft of Claim 20 further comprising compensating said damping torque command signal to configure spectral content of said damping torque command signal and thereby, generating a compensated torque command signal, wherein said compensating includes filtering configured facilitate at least one of tailoring said tactile feedback, maintaining stability of said steer-by-wire system.

Claim 24. The method for steering a watercraft of Claim 20 wherein said helm command signal is responsive to a combination of an assist torque command and a return torque command, and wherein said assist torque command is responsive to said compensated torque command signal and said watercraft speed signal; and said return torque command is responsive to said helm position signal and said watercraft speed signal.

Claim 25. The method for steering a watercraft of Claim 20 further comprising calculating and producing a variable steering ratio signal in response to said helm position signal and said watercraft speed signal.

Claim 26. The method for steering a watercraft of Claim 20 wherein said generating said directional command signal is based on said helm position signal, said helm torque signal, and said variable steering ratio signal.

Claim 27. The method for steering a watercraft of Claim 20 wherein said tactile feedback includes at least one of: a reaction force to an operator; an on center detent as a helm control moves thru a center position; and variable control stops to resist helm motion beyond a selected threshold.

Claim 28. The method for steering a watercraft of Claim 20 further including generating a torque command signal in a helm control system such that said helm control system exhibits a bandwidth sufficient to facilitate a torque control process generating said helm command signal to facilitate maintaining stability of said steering.

Claim 29. The method for steering a watercraft of Claim 20 wherein said helm control system comprises a helm control unit and a helm dynamics unit, said helm control unit is responsive to said helm torque command signal and said helm torque signal and generates a torque command signal, said helm dynamics unit is responsive to said torque command signal and provides a reaction torque in response thereto to an operator.

Claim 30. The method for steering a watercraft of Claim 29 wherein said helm control unit includes a compensator configured to characterize spectral content of said torque command signal to facilitate at least one of maintaining stability of said helm control system and increasing bandwidth of said helm control system.

Claim 31. The method for steering a watercraft of Claim 20 further including generating a position command signal in a direction control system such that said direction control system exhibits a bandwidth sufficient to facilitate a position control process generating said rudder command signal to facilitate maintaining stability of said steering.

Claim 32. The method for steering a watercraft of Claim 20 wherein said direction control system comprises a rudder control unit and a rudder dynamics unit, said rudder control unit is responsive to said directional command signal and said rudder position signal and generates a position command signal; said rudder dynamics unit is responsive to said position command signal and provides a rudder position in response thereto.

Claim 33. The method for steering a watercraft of Claim 32 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal to facilitate at least one of maintaining stability of said direction control system and increasing bandwidth of said direction control system.

Claim 34. The method for steering a watercraft of Claim 20 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal such that said direction control system exhibits a bandwidth sufficient to facilitate generation of a rudder command signal by a position control process to maintain stability of said steer-by-wire system.

Claim 35. The method for steering a watercraft of Claim 20 further including commanding a lateral thruster in cooperation with a rudder dynamics unit directing thrust to provide at least one of substantially lateral control and substantially yaw control to facilitate at least one of low speed and docking operations; wherein said lateral thruster is responsive to at least one of a port command and a starboard command.

Claim 36. The method for steering a watercraft of Claim 20 further including:

receiving an inclination signal from an inclination sensor; and

generating and providing a command to at least one of an I/O trim and a trim tab to control watercraft inclination.

Claim 37. The method for steering a watercraft of Claim 36 wherein said trim tab comprises a port trim tab and starboard trim tab to facilitate lateral inclination control.

Claim 38. The storage medium encoded with a machine-readable computer program code for steering a watercraft, said storage medium including instructions for causing a computer to implement a method comprising:

receiving a watercraft speed signal;

receiving a helm position signal

receiving a helm torque sensor signal;

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm torque signal , said helm position signal and said watercraft speed signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said watercraft speed signal, said rudder position signal, and said helm position signal to control direction of said watercraft.

Claim 39. The computer data signal for steering a watercraft, said computer data signal including instructions for causing a computer to implement a method comprising:

receiving a watercraft speed signal;

receiving a helm position signal

receiving a helm torque sensor signal;

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm torque signal , said helm position signal and said watercraft speed signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said watercraft speed signal, said rudder position signal, and said helm position signal to control direction of said watercraft.

Claim 40. A watercraft steer-by-wire control system comprising:

a direction control system responsive to a directional command signal for steering a watercraft, said direction control system including a rudder position sensor to measure and transmit a rudder position signal

a helm control system responsive to a helm command signal for receiving a directional input to a helm from an operator and providing tactile feedback to an operator, said helm control system including a helm position sensor to produce and transmit a helm position signal a master control unit in operable communication with said helm control system, and said direction control system;

said master control unit includes a position control process for generating said directional command signal in response to said helm position signal;

Claim 41. The watercraft steer-by-wire control system of Claim 1 further including a watercraft speed sensor for producing a watercraft speed signal and wherein said position control process is responsive to said watercraft speed signal.

Claim 42. The watercraft steer-by-wire control system of Claim 1 further including a watercraft mode selector for producing a mode selection signal and wherein said position control process is responsive to said mode selection signal.

Claim 43. The watercraft steer-by-wire control system of Claim 1 further including a rudder force sensor in operable communication with said rudder control system to produce and transmit a rudder force signal and wherein at least one of said rudder control system and a torque control process is responsive to said rudder force signal.

Claim 44. The watercraft steer-by-wire control system of Claim 1 further including a torque sensor to produce and transmit a helm torque signal said master control unit includes a torque control process for generating said helm command signal based on said helm torque signal, said helm position signal and said watercraft speed signal.

Claim 45. The watercraft steer-by-wire control system of Claim 5 wherein said torque control process includes an active damping process wherein a damping torque command signal is generated based on a time rate of change of said helm position signal and modified by said helm torque signal and said watercraft speed signal.

Claim 46. The watercraft steer-by-wire control system of Claim 5 wherein said torque control process implements a compensator to configure spectral content of a damping torque command signal thereby generating a compensated torque command signal, said compensator is configured to facilitate at least one of a modification of the spectral content of said tactile feedback and maintaining stability of said watercraft steer-by-wire control system.

Claim 47. The watercraft steer-by-wire control system of Claim 5 wherein said torque control process further implements a feel process comprising an assist sub-process responsive to a compensated torque command signal and said watercraft speed signal, which generates an assist torque command and a return sub-process responsive to said helm position signal and said watercraft speed signal, which generates a return torque command.

Claim 48. The watercraft steer-by-wire control system of Claim 1 wherein said position control process calculates and produces a variable steering ratio signal.

Claim 49. The watercraft steer-by-wire control system of Claim 9 wherein said variable steering ratio is response to at least one of said helm position signal, a helm torque signal, a watercraft speed signal, and watercraft mode selector for producing a mode selection signal.

Claim 50. The watercraft steer-by-wire control system of Claim 1 wherein said position control process further comprises a directional command process that calculates a theta correction and generates a theta corrected directional command signal from a variable steering ratio signal, and said helm position signal.

Claim 51. The watercraft steer-by-wire control system of Claim 11 wherein said theta corrected directional command signal, is based on a helm torque signal.

Claim 52. The watercraft steer-by-wire control system of Claim 1 wherein said tactile feedback includes at least one of: reaction torque to an operator; an on center detent as a helm moves thru a center position; and variable control stops to resist helm motion beyond a selected threshold.

Claim 53. The watercraft steer-by-wire control system of Claim 5 wherein said helm control system comprises a closed loop control system responsive to said helm command signal and said helm torque signal.

Claim 54. The watercraft steer-by-wire control system of Claim 5 wherein said helm control system configured to exhibit a bandwidth sufficient to facilitate said torque control process maintaining stability of said watercraft steer-by-wire system.

Claim 55. The watercraft steer-by-wire control system of Claim 5 wherein said helm control system comprises a helm control unit and a helm dynamics unit; said helm control unit is responsive to said helm command signal and said helm torque sensor signal and generates a torque command signal; said helm dynamics unit is responsive to said torque command signal and provides said tactile feedback in response thereto to an operator.

Claim 56. The watercraft steer-by-wire control system of Claim 16 wherein said helm control unit includes a compensator configured to characterize spectral content of said torque command signal to facilitate at least one of maintaining stability of said helm control system and increasing bandwidth of said helm control system.

Claim 57. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system is configured to exhibit a bandwidth sufficient to facilitate said position control process maintaining stability of said watercraft steer-by-wire system.

Claim 58. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system comprises a closed loop control system responsive to said directional command signal and said rudder position signal.

Claim 59. The watercraft steer-by-wire control system of Claim 1 wherein said direction control system comprises a rudder control unit and a rudder dynamics unit; said rudder control unit is responsive to said directional command signal and a rudder position signal and generates a position command signal; said rudder dynamics unit is responsive to said position command signal and provides a rudder position in response thereto.

Claim 60. The watercraft steer-by-wire control system of Claim 20 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal to facilitate at least one of maintaining stability of said direction control system and increasing bandwidth of said direction control system.

Claim 61. The watercraft steer-by-wire control system of Claim 1 further including a lateral thruster in operable communication and cooperation with a rudder dynamics unit directing thrust to provide at least one of substantially lateral control and substantially yaw control to facilitate at least one of low speed and docking operations; wherein said lateral thruster is responsive to at least one of a port command and a starboard command.

Claim 62. The watercraft steer-by-wire control system of Claim 22 wherein said at least one of said port command and said starboard command is based on at least one of a selected directional input from an operator, an operator input at said helm, and a mode selection signal.

Claim 63. The watercraft steer-by-wire control system of Claim 23 wherein at least one of a port command and a starboard command is based on a selected directional input from an operator at said helm in excess of a selected threshold, wherein said lateral thruster is responsive to pulse width modulation scheme with a duty cycle responsive to at least one of a magnitude of said selected directional input, and a selected threshold from a variable stop of said helm control.

Claim 64. The watercraft steer-by-wire control system of Claim 22 wherein said a lateral thruster is responsive to a selected gear or direction.

Claim 65. The watercraft steer-by-wire control system of Claim 1 further including an inclination control system comprising:

an inclination sensor in operable communication with said master control unit;

at least one of an I/O trim and a trim tab, with an actuator in operable communication with said master control unit; and

wherein said master control unit provides a trim command to at least one of said I/O trim and said trim tab to control watercraft inclination.

Claim 66. The watercraft steer-by-wire control system of Claim 26 wherein said trim tab comprises a port trim tab and starboard trim tab to facilitate lateral inclination control.

Claim 67. A method for directing a watercraft with a watercraft steer-by-wire system comprising:

receiving a helm position signal;

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm position signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said rudder position signal, and said helm position signal to control direction of said watercraft.

Claim 68. The method for steering a watercraft of Claim 28 further comprising receiving a watercraft speed signal and wherein at least one of said generating a helm command is further based on said watercraft speed signal and said generating a directional command signal is further based on said watercraft speed signal.

Claim 69. The method for steering a watercraft of Claim 28 further including a watercraft mode selector for producing a mode selection signal and wherein said generating a directional command signal is responsive to said mode selection signal.

Claim 70. The method for steering a watercraft of Claim 28 further comprising:

receiving a rudder force signal and wherein said a helm command signal is also based on said rudder force signal; and

generating a directional command signal to a direction control system based on said watercraft speed signal, said helm position signal, and at least one of said rudder position signal and said rudder force signal.

Claim 71. The method for steering a watercraft of Claim 28 further comprising receiving a helm torque signal and wherein said generating a helm command is further based on said helm torque signal.

Claim 72. The method for steering a watercraft of Claim 32 further comprising:

generating damping torque command signal responsive to said helm torque signal, said helm position signal and a watercraft speed signal; wherein said damping torque command signal is responsive to a time rate of change of said helm position signal and said helm command signal is based on said damping torque command signal.

Claim 73. The method for steering a watercraft of Claim 33 further comprising compensating said damping torque command signal to configure spectral content of said damping torque command signal and thereby, generating a compensated torque command signal, wherein said compensating includes filtering configured facilitate at least one of tailoring said tactile feedback, maintaining stability of said steer-by-wire system.

Claim 74. The method for steering a watercraft of Claim 33 wherein said helm command signal is responsive to a combination of an assist torque command and a return torque command, and wherein said assist torque command is responsive to said compensated torque command signal and said watercraft speed signal; and said return torque command is responsive to said helm position signal and said watercraft speed signal.

Claim 75. The method for steering a watercraft of Claim 28 further comprising calculating and producing a variable steering ratio signal in response to at least one of said helm position signal, a helm torque signal, a watercraft speed signal, and watercraft mode selector for producing a mode selection signal l.

Claim 76. The method for steering a watercraft of Claim 36 wherein said generating said directional command signal is based on said helm position signal, said helm torque signal, and said variable steering ratio signal.

Claim 77. The method for steering a watercraft of Claim 28 wherein said tactile feedback includes at least one of: a reaction force to an operator; an on center detent as a helm control moves thru a center position; and variable control stops to resist helm motion beyond a selected threshold.

Claim 78. The method for steering a watercraft of Claim 28 further including generating a torque command signal in a helm control system such that said helm control system exhibits a bandwidth sufficient to facilitate a torque control process generating said helm command signal to facilitate maintaining stability of said steering.

Claim 79. The method for steering a watercraft of Claim 39 wherein said helm control system comprises a helm control unit and a helm dynamics unit, said helm control unit is responsive to a helm torque command signal and said helm torque signal and generates a torque command signal, said helm dynamics unit is responsive to said torque command signal and provides a reaction torque in response thereto to an operator.

Claim 80. The method for steering a watercraft of Claim 40 wherein said helm control unit includes a compensator configured to characterize spectral content of said torque command signal to facilitate at least one of maintaining stability of said helm control system and increasing bandwidth of said helm control system.

Claim 81. The method for steering a watercraft of Claim 28 further including generating a position command signal in a direction control system such that said direction control system exhibits a bandwidth sufficient to facilitate a position control process generating said directional command signal to facilitate maintaining stability of said steering.

Claim 82. The method for steering a watercraft of Claim 28 wherein said direction control system comprises a rudder control unit and a rudder dynamics unit, said rudder control unit is responsive to said directional command signal and said rudder position signal and generates a position command signal; said rudder dynamics unit is responsive to said position command signal and provides a rudder position in response thereto.

Claim 83. The method for steering a watercraft of Claim 43 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal to facilitate at least one of maintaining stability of said direction control system and increasing bandwidth of said direction control system.

Claim 84. The method for steering a watercraft of Claim 43 wherein said rudder control unit includes a compensator configured to characterize spectral content of said position command signal such that said direction control system exhibits a bandwidth sufficient to facilitate generation of a rudder command signal by a position control process to maintain stability of said steer-by-wire system.

Claim 85. The method for steering a watercraft of Claim 28 further including commanding a lateral thruster in cooperation with a rudder dynamics unit directing thrust to provide at least one of substantially lateral control and substantially yaw control to facilitate at least one of low speed and docking operations; wherein said lateral thruster is responsive to at least one of a port command and a starboard command.

Claim 86. The method for steering a watercraft of Claim 46 wherein said at least one of said port command and said starboard command is based on at least one of a selected directional input from an operator, an operator input at said helm, and a mode selection signal.

Claim 87. The method for steering a watercraft of Claim 47 wherein at least one of a port command and a starboard command is based on a selected directional input from an operator at said helm in excess of a selected threshold, wherein said lateral thruster is responsive to pulse width modulation scheme with a duty cycle responsive to at least one of a magnitude of said selected directional input, and a selected threshold from a variable stop of said helm control.

Claim 88. The method for steering a watercraft of Claim 46 wherein said a lateral thruster is responsive to a selected gear or direction.

Claim 89. The method for steering a watercraft of Claim 28 further including:

receiving an inclination signal from an inclination sensor; and

generating and providing a command to at least one of an I/O trim and a trim tab to control watercraft inclination.

Claim 90. The method for steering a watercraft of Claim 50 wherein said trim tab comprises a port trim tab and starboard trim tab to facilitate lateral inclination control.

Claim 91. The storage medium encoded with a machine-readable computer program code for steering a watercraft, said storage medium including instructions for causing a computer to implement a method comprising:

receiving a helm position signal

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm position signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said rudder position signal, and said helm position signal to control direction of said watercraft.

Claim 92. The computer data signal for steering a watercraft, said computer data signal including instructions for causing a computer to implement a method comprising:

receiving a helm position signal

receiving a rudder position signal;

generating a helm command signal to a helm control system based on said helm position signal to provide tactile feedback to an operator; and

generating a directional command signal to a direction control system based on said rudder position signal, and said helm position signal to control direction of said watercraft.